Team EE4 pm11

SSV Case 1

VentuSolaris

Steven Dendooven, Jeroen Renders, Martijn Schaeken, Simon Putseys, Frederik Vercammen
18-3-2014

Inhoud

List of figures

List of tables

Engineering

SSV case 1

Characteristics of the solar panel :

In the experiment we measured the voltage and current delivered by the solar panel. First we measured the short circuit current and open circuit voltage without a resistor connected to the solar panel. Our measurements aren't accurate because our solar panel was getting too hot.

spanning	stroom	vermogen	m-waardes
8,55	0,07	0,5985	1,372414855
8,51	0,08	0,6808	1,368402891
8,46	0,09	0,7614	1,353166408
8,4	0,09	0,756	1,353166408
8,35	0,09	0,7515	1,345111846
8,3	0,1	0,83	1,339556978
7,89	0,11	0,8679	1,275840484
6,7	0,11	0,737	1,083413338
5,61	0,11	0,6171	0,907156542
4,49	0,11	0,4939	0,72604864
3,75	0,12	0,45	0,607594136
2,45	0,12	0,294	0,396961502
1,57	0,12	0,1884	0,254379412
0,42	0,12	0,0504	0,068050543
0,3	0,12	0,036	0,048607531

Table 1: Measured voltage and current and calculated power and diode factor.

We plotted these measurements, which resulted in the following graphs. Because of the error in our measurements the graphs are not very accurate. The current is too low and so is the power.

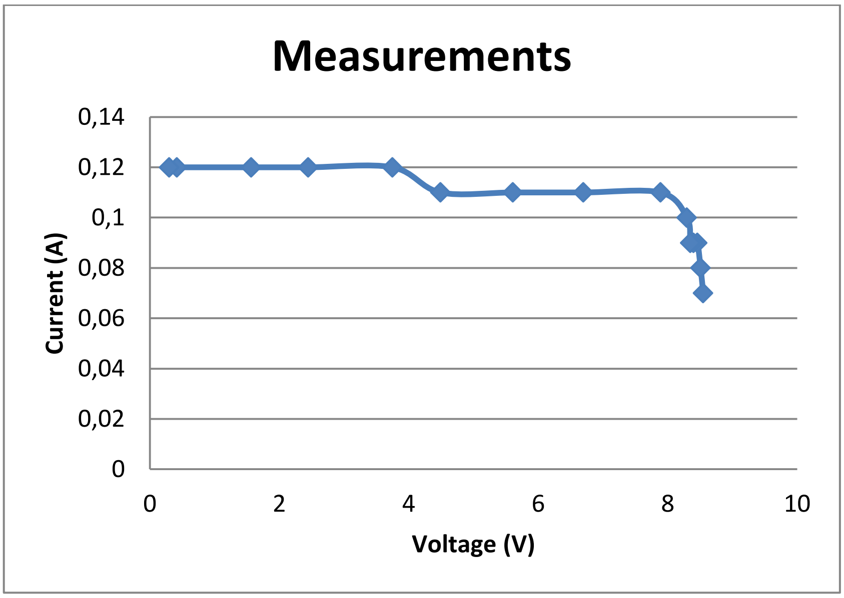


Figure 1: Graph of our measurements (Voltage and Current)

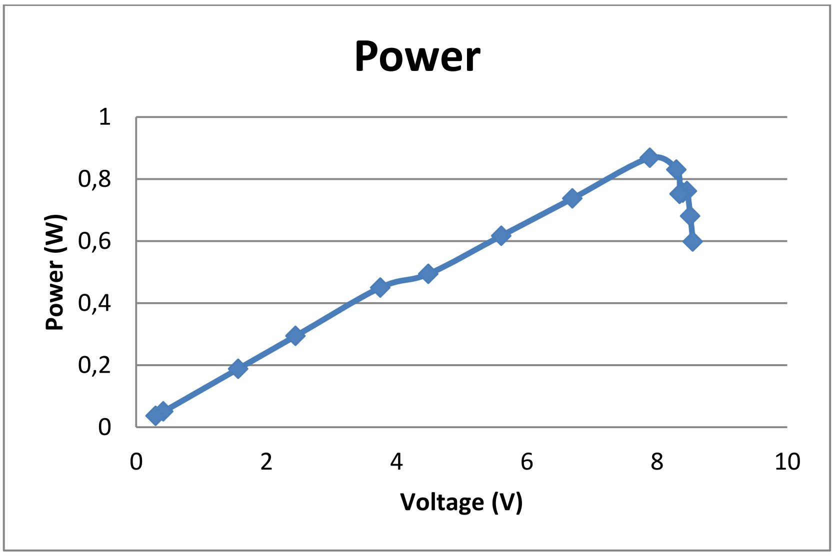


Figure 2: Power graph (Power in function of Voltage)

With these measurements we calculated the diode factor of our solar panel and the power delivered. We did this by filling in all the factors of the formula:

$$Iout = Isc - Is(2.71828^{(\frac{U}{mNUr})} - 1);$$

All the variables we had to fill in this formula were given except for the voltage, the current and the diode factor. The short circuit current and the number of solar cells were measured by our team. Is was 10*10^(-8) Ampère, this is the reverse saturation current. The diode factor m and N, the number of solar cells, were to be decided by us. The thermal voltage was given to us and was 25,7 mV. Isc, the short circuit current was 0.45 A. The open circuit voltage we measured was 8.55V. When we filled in our different measurements of the current and the voltage we found different diode factors m. We calculated the average diode factor which turned out to be 0.89. We plotted the graph of the

current in function of the voltage and we got the result. We optimized the graph with a better diode factor of 1.29 and the correct short circuit current of 0.9 A, given to us by the coaches.

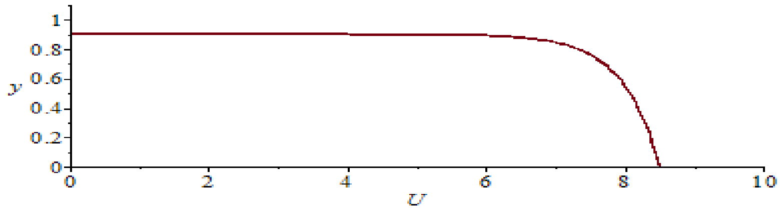


Figure 3: The characteristic of the current in function of the voltage.

In this graph we can clearly see the short circuit current of 0.9 A and the open circuit voltage of 8.66 V. This is the graph for a diode factor of 1.29 which is the value we will use in our further calculations. This is the optimized diode factor.

We calculated m in the following manner:

$$m = \frac{U}{NUrln(\frac{Isc - Iout}{Is} + 1)}$$

We also plotted the power delivered by the solar panel in function of the voltage across the solar panel.

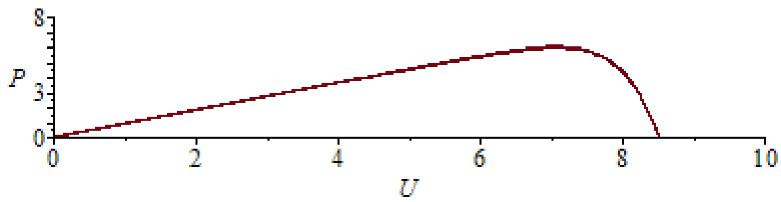


Figure 4: The power delivered by the solar panel in function of the voltage.

In this graph we see that the power reaches a maximum at 7.08 V. We found this value by deriving the equation of the Power curve and by deciding for which voltage it equals 0.

To calculate the error on our calculations we need to search for the error on the digital multimeter. With this error we can calculate the final error on our calculation.

We calculate the error on one measurement in the following manner:

$$\Delta(Isc - Iout) = \sqrt{(\frac{\Delta Isc}{Isc})^2 + (\frac{\Delta Iout}{Iout})^2}$$

$$\Delta \ln\left(\frac{(Isc - Iout) \pm \Delta(Isc - Iout)}{Is} + 1\right) = \frac{\Delta(Isc - Iout)}{\frac{(Isc - Iout)}{Is} + 1}$$

$$\Delta m = m\sqrt{(\frac{\Delta U}{U})^2 + (\frac{\Delta \ln\left(\frac{(Isc - Iout) \pm \Delta(Isc - Iout)}{Is} + 1\right)}{NUrln\left(\frac{Isc - Iout}{Is} + 1\right)})^2}$$

When we calculate this for our working point U=7.09 V, Iout=1.01 A and Isc=1.03 A(the value of the open circuit current changed after we calculated this error to 0.9) we get:

$$m = 1.29 \pm 2 * 10^{-3}$$

Gear ratio and optimal mass

When we simplify the characteristics of the solar panel we get the following results.

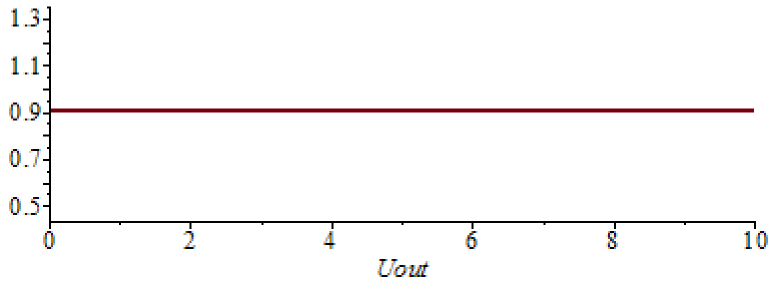


Figure 5: The simplified characteristic of the current in function of the voltage for the solar panel.

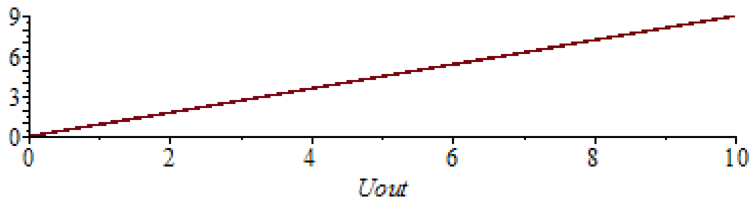


Figure 6: Simplified characteristic of the power in function of the voltage.

When we assume elastic collision with the formula:

$$Vend,ball = [(Mini,ball - Mini,SSV) \times Vini,ball + 2Mini,SSV \times Vini,SSV]/(Mini,SSV + Mini,ball)$$

We fill in the mass of the ball, 735±10 gram and we set the initial speed of the ball equal to zero so we get an equation for Vend,ball.

$$V_{end,ball} = \frac{2massV_{car}}{mass_{car} + mass_{ball}}$$

Now we search an equation for V_{car} in function of the mass of the car and the gear ratio. To find the gear ratio we look at the free body of the wheel. When we apply the law of newton, ΣF=ma, with ΣF the force of the wheel delivered by the motor, this force equals the torque on the wheel divided by the radius of the wheel. The acceleration is found by applying the formulas for constant acceleration.

$$x = x_0 + v_0 t + \frac{a^2 t}{2}$$

$$v = v_0 + \frac{at}{2}$$

When we assume that x_0 and v_0 equal 0 and the final position x equals 10m we find the following formula for the acceleration.

$$a = \frac{{V_{car}}^2}{20}$$

If we use this equation for our newton law, and we know that the torque of the wheel equals the torque of the motor multiplied by the gear ratio Gr we get the following function.

$$\frac{T_M Gr}{r_{wheel}} = \frac{mass {V_{car}}^2}{20}$$

To find V_{car} we use the gear ratio and the rotational speed of the motor.

$$Gr = \frac{w_M}{V_{car}} r_{wheel}$$

If we use this V_{car} in the previous equation we find our gear ratio Gr in function of the mass, the rotational speed of the motor, the radius of the wheel r_{wheel} and the torque of the motor.

$$Gr = \sqrt[3]{\frac{((\frac{mass * {w_M}^2 * {r_{wheel}}^2}{20})r_{wheel}}{T_M}}$$

Taking all these equations into account we find $V_{end,ball}$ in function of the mass of the car.

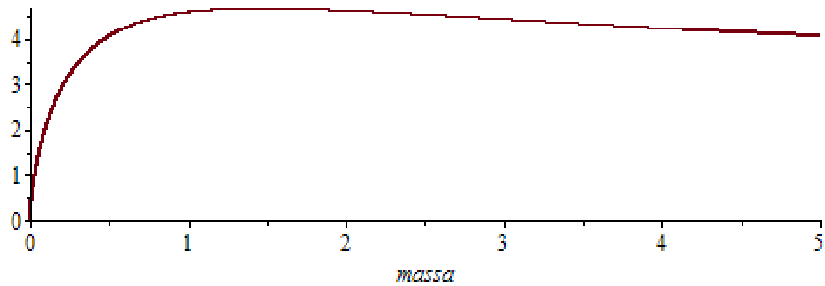


Figure 7: The speed of the ball in function of the mass of the car.

In this graph we see the speed getting to its maximum for a mass of 1.47 kg. This is the ideal mass to get the ball as high as possible after elastic collision between the car and the ball. We found this by setting the derivative of the target function to zero and finding the intersection with the x-axis.

Target function: $$V_{end,ball} = \frac{2mass * \frac{w_M}{\sqrt[3]{\frac{mass * {w_M}^2}{20}}}}{mass_{car} + mass_{ball}}$$

To predict the maximal height of the ball we calculate the initial speed of the ball with the rotational speed of the motor equal to 420 rad/s and the mass equal to 1.47 kg. The initial speed of the ball can be found in figure 5 at the ideal mass. This initial speed is 4.667 m/s. If we assume that all kinetic energy is transformed to potential energy, we can calculate the maximal height of the ball.

$$\frac{mass_{ball} {v_{end,ball}}^2}{2} = mass_{ball} g h_{ball}$$

$$\text{With } g = 9.81 m/s^2$$

When we calculate this with the velocity of the ball we found we get a maximal height of 1.11 m.

Because of the analytic calculations we can make important decisions about the car, like mass, height, material, shape, gear ratio etc. This is important so you don't waste time rebuilding multiple times. A disadvantage is us making assumptions and simplifications and it is an ideal case.

Simulation

We simulated our SSV in Matlab for 10 different masses and ratios and we picked the best mass from the graphs. With this best mass we simulate again with the 10 gear ratios from before. In this way we get the best mass and its matching best gear ratio. The ideal mass we interpreted from our graphs is 1.1kg . For this mass we search the best gear ratio .The graphs are shown below.

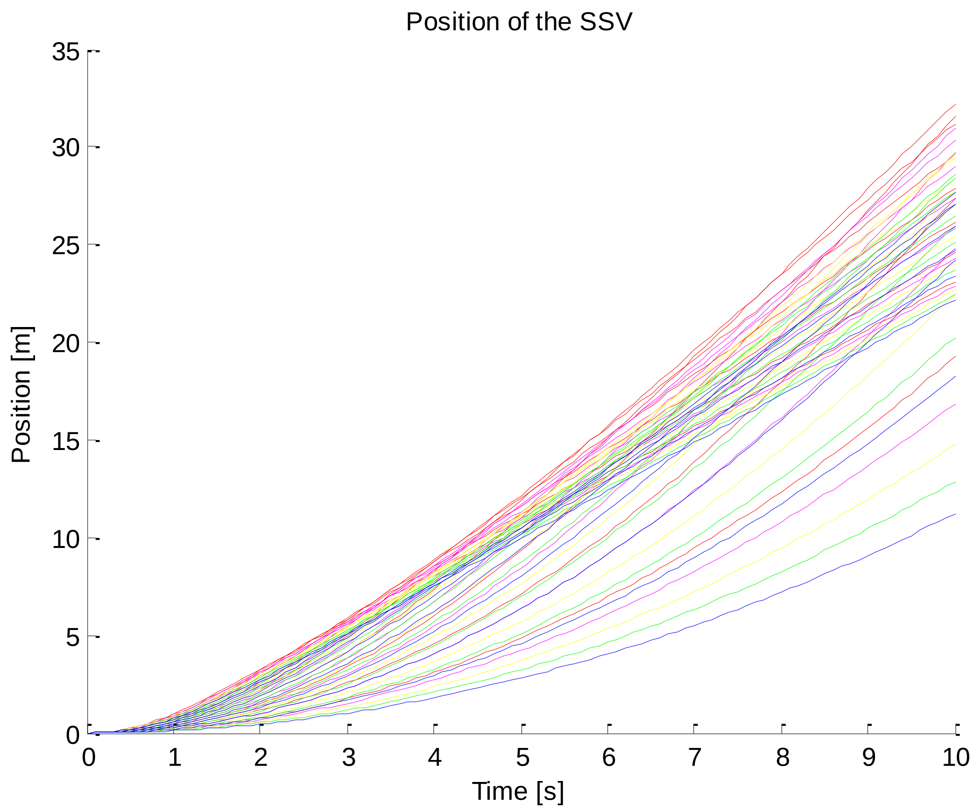


Figure 8: Position for a mass between 1.4 and 1.8 kg and a gear ratio from 4 to 13.

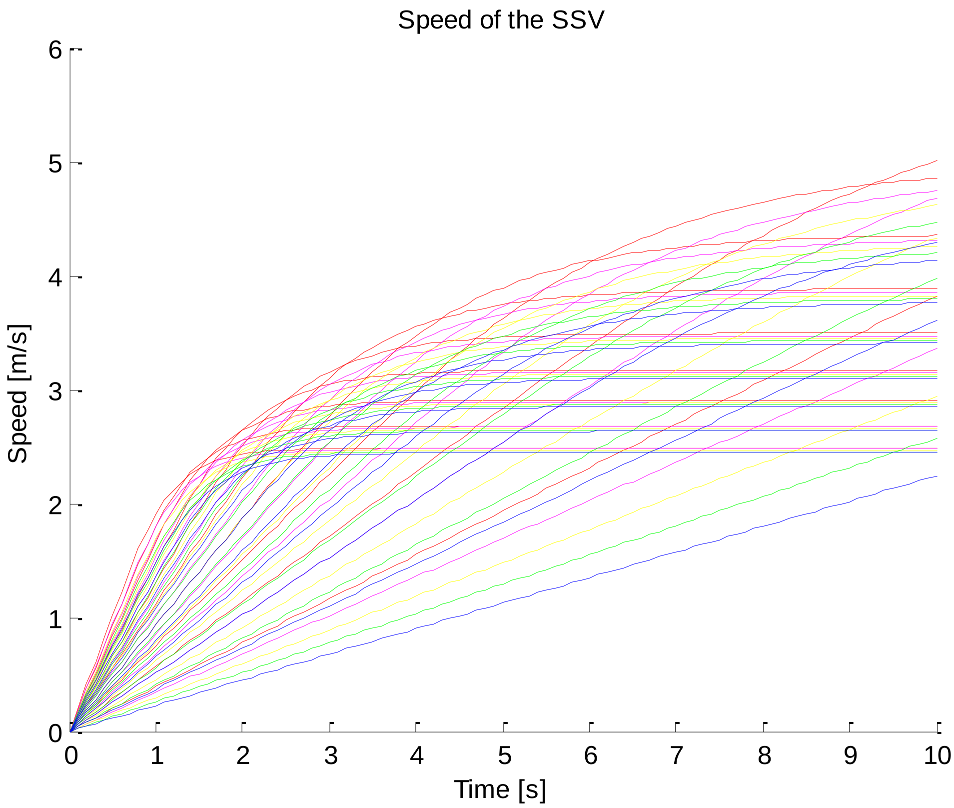


Figure 9: Speed for a mass between 1.4 and 1.8 kg and a gear ratio from 4 to 13.

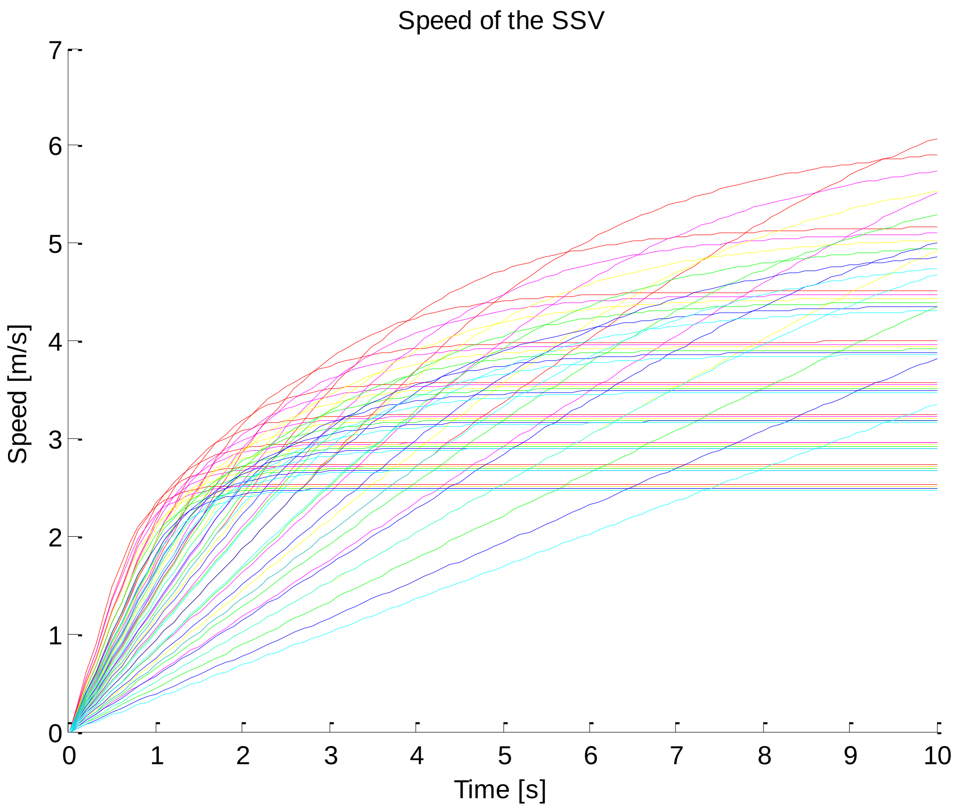


Figure 10: Speed for a mass between 1 and 1.5 kg and a gear ratio from 4 to 13.

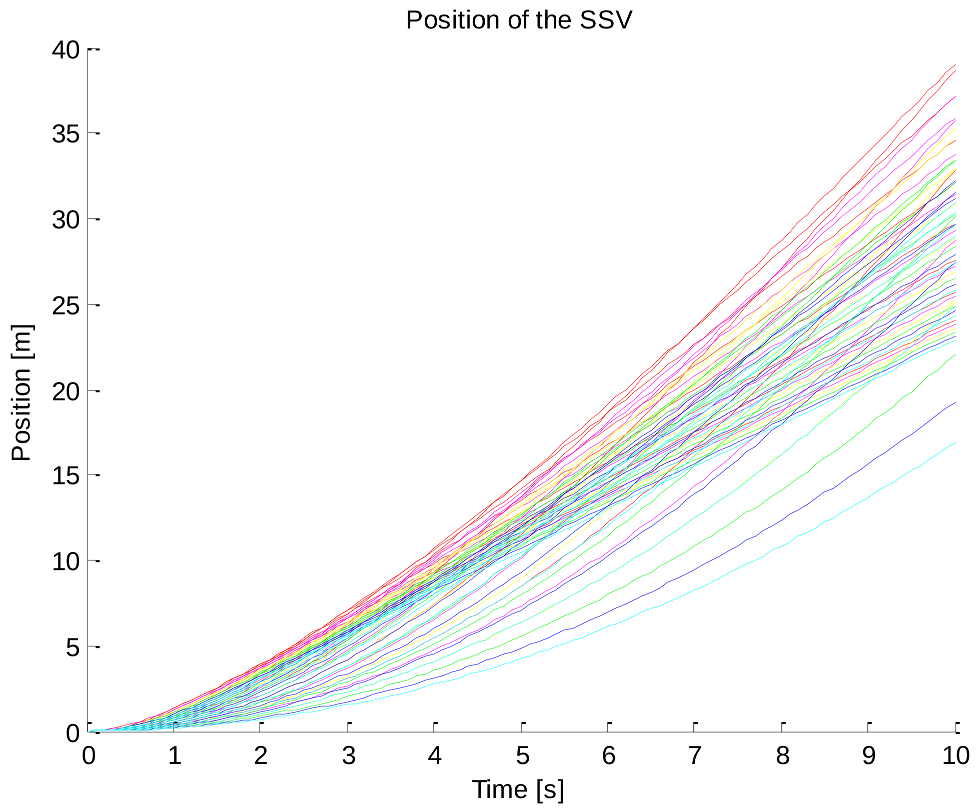


Figure 11: Position for a mass between 1 and 1.5 kg and a gear ratio from 4 to 13.

If we plot our target function for a mass of 1.1 kg and a gear ratio varying from 4 to 10, which is the speed of the ball in function of the mass and the gear ratio we get the following graph. We clearly see that the velocity of the ball will be the greatest for a gear ratio of 6, which is the yellow graph.

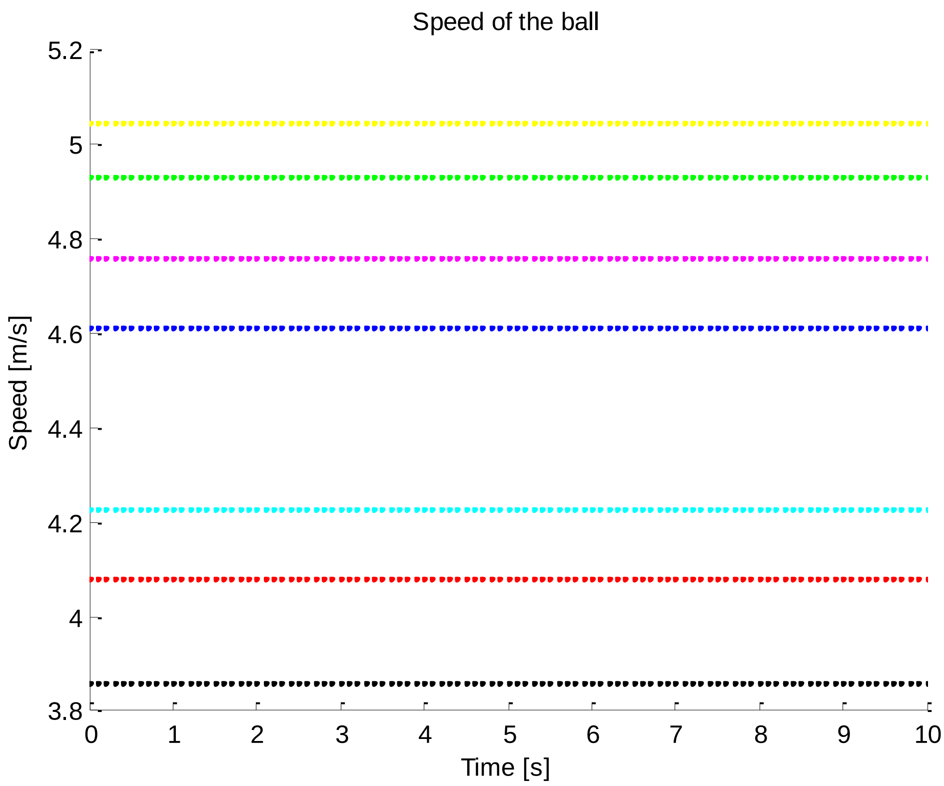


Figure 12: The velocity of the ball for different gear ratios between 4 and 10.

When we plotted our target function for the same mass but for a gear ratio varying from 5.9 to 6.5 we get the graph below. We see a maximal ball velocity for a gear ratio of 6.1, the yellow graph.

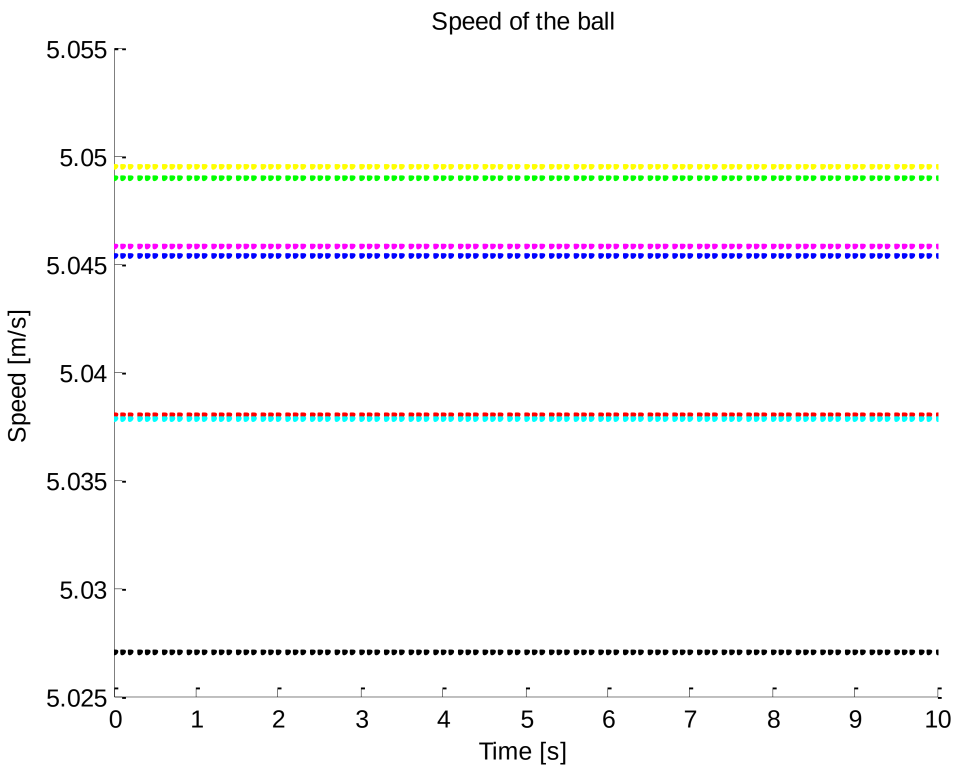
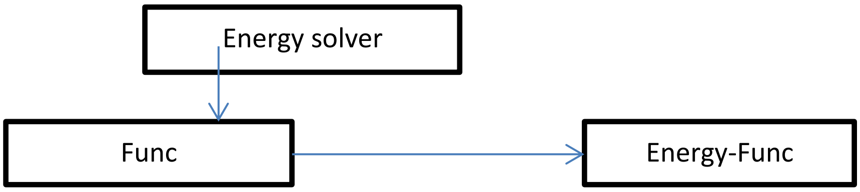


Figure 13: The velocity of the ball for different gear ratios between 5.9 and 6.5.

In the next section we answer to the questions between the Matlab lines.

a. Draw a flow chart of the relation between these files.



The Energy solver runs true the entire program and uses the smaller sub programs Func. This small program fills in all the variables of the solar panel, the motor and other important variables in to Energy solver. Func uses the program Energy-Func. This part is where the user fills in the variables that are being filled in by Func in Energy Solver.

b. Explain the following line: [t,s] = ode15s(@Energy_Func,(t0:tf/100:tf),x0,options); What are t and s?

'ode15s' is used to solve a differential equation, this is being done by using laplace transformation to s with steps of 0.01s. 'x0' refers to the initial values to help solve the differential equation. These are defined in line 16 of the code. The reference to Energy_Func is used because the equation is found in that part.

c. What is done here and why?

The differential equation is solved for different values, in steps of 0.1 from 1 to 10.

d. What is the function of this file?

The variables are defined and the functions are worked out.

e. What are dx, t and x? Why are they in this line? Does there exact name matter for the program?

Their exact name doesn't matter for the program. Dx is defined at the bottom of the page, and is the energy function. For the other two variables t is the time, and x is the distance travelled by te SSV.

f. Does the exact name of these parameters matter? Why (not)?

The exact name of the parameters doesn't really matter, as long as they are the same in every tab or every formula that is defined.

g. Describe these parameters and give their units.

Solar Panel:

Isc=0.9 A; short circuit current

Is=1e-8 A; Saturation current

Ur=0.0257 V; Terminal voltage

m= 1.29 no dimension; diode constant

N= 16 no dimension; number of cells

DC – Motor:

w=420;

R= 3.36 Ohm resistance of the armature

Ce= 0.00089285 V/rmp

Air resistance:

Cw= 0.065 no dimension

A= 0.20*0.15 m^2 area

rho= 1.275 kg/m^3 density

Rolling resistance:

g=9.81 m/s^2; gravity

Crr= 0.035 no dimension; drag resistance

SSV:

r = 0.03 m wheel radius

h. What is x(2)?

X(2) is the speed after two seconds, after two seconds the air resistance needs to be taken into account.

i. What is TolFun? What is fzero and why do we call it here? What are sol and f?

With fzero, the zero point of the function f is defined.

j. Explain the energy equations. What is the difference?

In the first equation the air resistance isn't taken into account, this assumption is made because the speed of the SSV isn't that hight untill two seconds after the start. After two seconds the speed is

high enough to take the air resistance into account, so a different equation is used after two seconds.

k. What is the function of this file. How is it used?

In this file de functions for the behavior of the solar panel and the DC – Motor are melted together into one equation. Because the used variables are global, they can be used in different programs at one moment. To make the overall program a bit more comprehensible it is divided into three smaller programs each with their own function.

l. What is f?

f is constructed out of three parts, U is the open circuit voltage. The second term is the voltage of the solar panel and the third term is the voltage used by the DC – Motor.

If we plot a graph for our results of the ideal mass and the ideal gear ratio we get the following result. Our best gear ratio and mass are the following.

$$m = 1.1 \text{ kg}$$

$$gear\ ratio = 6.1$$

Figure 14: The graph of the position of the car.

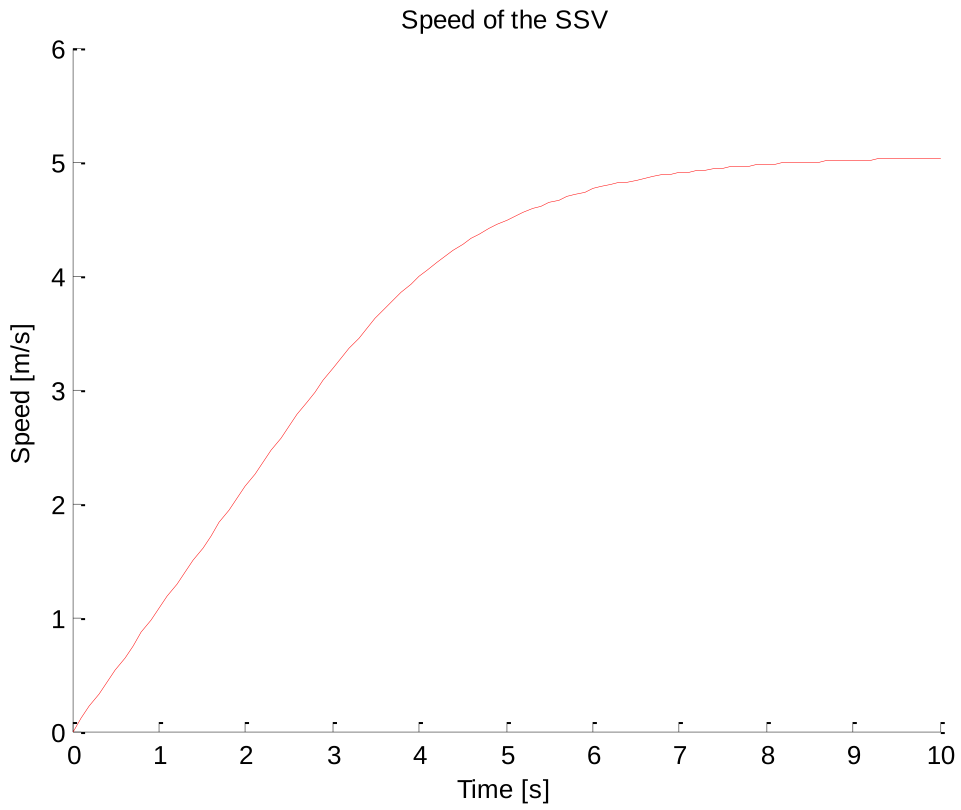


Figure 15: The graph of the velocity of the car.

When we calculate the speed of the car at the end of the track we can calculate the maximal height of the ball. The speed of the car at a position of 10 m, which it reaches after 4.4 sec will be 4.221 m/s. With this speed of the car after 10 m, the speed of the ball will be 5.05 m/s at collision between the car and the ball.

$$h = \frac{v^2}{2 * g}$$

$$\text{met } g = 9.81\ m/s^2$$

This gives us a maximal height for the ball of 1.29 m.

When we compare these results with our results from the analytic calculations we notice the velocity and the height being higher in the Matlab simulation. When we simulate the behavior of the car we get an ideal mass of 1.1 kg and a gear ratio of 6.1, which is a lower mass than the one we calculated analytically. But it is a higher gear ratio than the analytically calculated one.

List of assumptions and simplifications

We assumed constant acceleration for the calculations of the gear ratio Gr and the optimal mass of the car. We also simplified the method to find the rotational speed of the motor. We estimated the working point of the motor characteristic and the solar panel characteristic. We didn’t take the air resistance and the rolling resistance into account yet for these calculations. Because of this our car will drive slower during the race and the ball will get less high on the ramp. We also assumed elastic

collision between the ball and the car, so in a real life situation there will be energy loss in the collision. This assumption makes it possible to calculate the maximal height of the ball. We got a value for the short circuit current from our coach which we used in the collected.

We do a sensitivity analysis on the value of the diode factor m. If we make m larger the working point of our solar panel and our motor changes, the ideal voltage will get larger but the current stays the same. The rotational speed of our motor would also increase. The torque delivered by the motor will stay the same because it is dependent of the current which stays the same. These two things result in an increased power delivered by the motor. The gear ratio will also increase a lot which will result in an increased speed when the car hits the ball. This will result eventually in a higher maximal height of the ball on the ramp.

Bisection method

We search the intersection with the x-axis with the bisection method. As an example we do this with the following function.

$$f(x) = \frac{1}{2} + \sin\left(\frac{x}{2}\right) e^{\left(\sin\left(\frac{x}{3}\right)\right)} \, for \; x \in [0,10]$$

First we check if 0 lies in between the values of the interval.

$$f(0) = 0.5$$
$$f(10) = -0.2954$$

We see that the function hits 0 somewhere between those values so we take the average of the interval and calculate f(5).

$$f(5) = 2.119362673$$

f(5) >0 and f(10)<0, so the function is zero in between [5,10]. So we take the average 7.5 for the next iteration

$$f(7.5) = -0.53986265$$

We see that the function is zero in between [5,7.5] and iterate more.

$$f(6.25) = 0.5396629439$$
$$f(6.875) = -0.1180946389$$
$$f(6.5625) = 0.1852658234$$

Eventually we find a value for x which is the following:

$$f(6.74562547) = 0.0006068487 \approx 0$$

Now that we are familiar with the bisection method we can use it for our personal values. We use our optimal mass and gear ratio to look at the first second of our speed and position characteristic. When we plot this we get figure 14 and figure 15.

The equations of the position and the velocity are the following. They are found by using matlab figures.

$$x(t) = -0.03x^3 + 0.68x^2 - 0.14x - 0.0097$$

$$v(t) = -0.82x^2 + 1.3x - 0.066$$

When we apply the bisection method for the first second with an interval of 0.1s to these equations we get the following results.

First we calculate zero for the position function, so we check if zero lies in between 0 and 1.

$$x(0) = -0.0097$$
$$x(1) = 0.5003$$

We can see that zero does indeed lie in the interval so now we can start iterating. First we take the average of the interval which is 0.5.

$$x(0.5) = 0.08655$$

x(0.5)>0 so zero lies on the left hand side of the average, so now we take the average of the interval [0,.5], which is 0.25.

$$x(0.25) = -0.00266875$$

x(0.25)<0 so now we see that zero lies on the right hand side of t=0.25. So again we take the average of the interval [0.25,0.5]. After this we iterate a few more times according to the same method until we find a value for t.

$$x(0.375) = 0.0318429687$$
$$x(0.2626953125) = -0.00009519011$$

Eventually we find a value for t where the position function is almost 0:

$$x(0.2631835938) = 0.0000080205$$

Now we do the same for the speed function, we check if zero lies in between 0 and 1.

$$v(0) = -0.066$$
$$v(1) = 0.414$$

Again we can see that zero does indeed lie in the interval so now we can start iterating. First we take the average of the interval which is 0.5.

$$v(0.5)0.379$$

V(0.5)>0 so zero lies on the left hand side of the average, so now we take the average of the interval [0,.5], which is 0.25.

$$v(0.25) = 0.20775$$

v(0.25)>0 so zero still lies on the left hand side of t=0.25. So again we take the average of the interval [0,0.25]. After this we iterate a few more times according to the same method until we find a value for t.

$$v(0.125) = 0.0836875$$
$$v(0.0525516955) = 0.00005210896$$

Eventually we find a value for t where the position function is almost 0:

$$v(0.052520752) = 0.0000150655$$

Case Simulink

Simulating solar panel behavior.

The figure below is our simulation in Simulink of the solar panel.

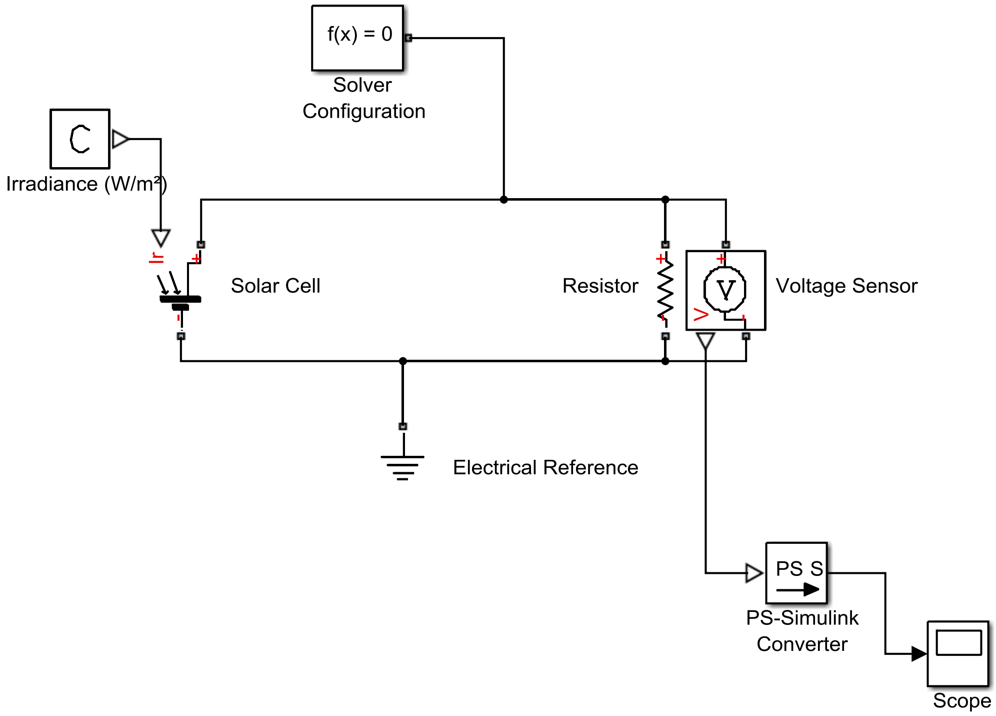


Figure 16: Our simulation of the solar panel.

We plot the current in function of the voltage for the solar panel connected to a resistor between 10 and 100 Ohm. We see some points appear on the graph. The line they form looks like the characteristic of the solar panel we drew in maple before. We also plotted the power in function of the voltage and this graph also resembles the graph we got before.

Below we paste a piece of the matlab code that plots the graphs.

```
clear all;
close all;

%%% Solar Power
Ir =  e^(-8)    ;
Is = 1e-8 ;
Isc =   0.9   ;
Voc =  8.55    ;
Ir0 = 700 ;    % irradiance used for measurements [W/m^2]
m =    16*1.29    ;
% if you use only 1 cell, you have to multiply your diode factor with the
% actual number of cells on the solar panel
```

```
V=[];
I=[];
P=[];
h1=figure
hold on
h2=figure
hold on

% replace these values for the resistance with relevant values
R_list=[10 20 30 40 50 60 70 80 90 100];

for i=1:length(R_list)
    R=R_list(i)

    sim('Solar_panel_model',1); % simulate Simulink model
"Solar_panel_model.mdl" for 1 s

    V = [V yout(end,1)];
    I = [I yout(end,2)];
    P = [P yout(end,3)];
end
hold off
figure(h1)
plot(V,I,'b*');
ylabel(Current [A]');
xlabel(Voltage [V]');
axis([0 10 0 1.5]);
set(gcf,'color',[1 1 1])

figure(h2)
plot(V,P,'r*');
ylabel('Power [W]');
xlabel('Voltage [V]');
axis([0 10 0 10]);
set(gcf,'color',[1 1 1])
```

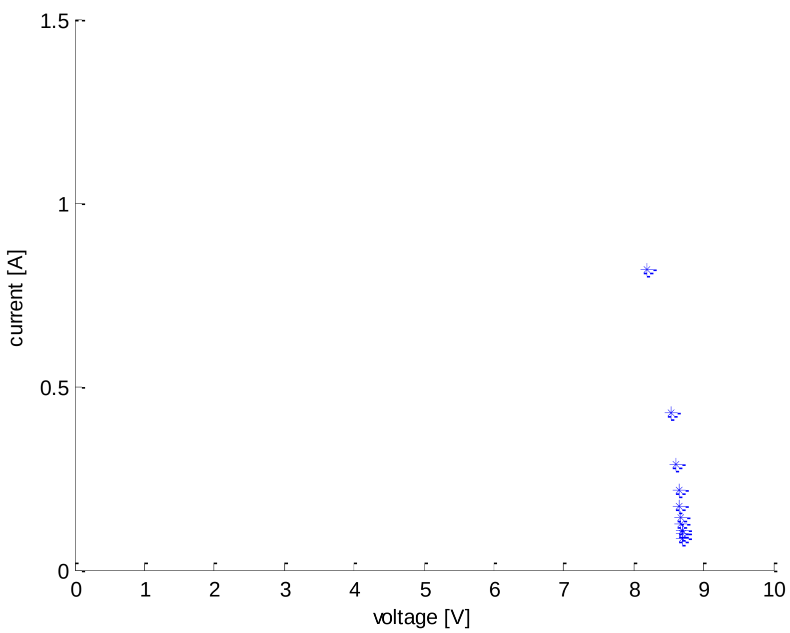


Figure 17: Current in function of the voltage for the solar panel.

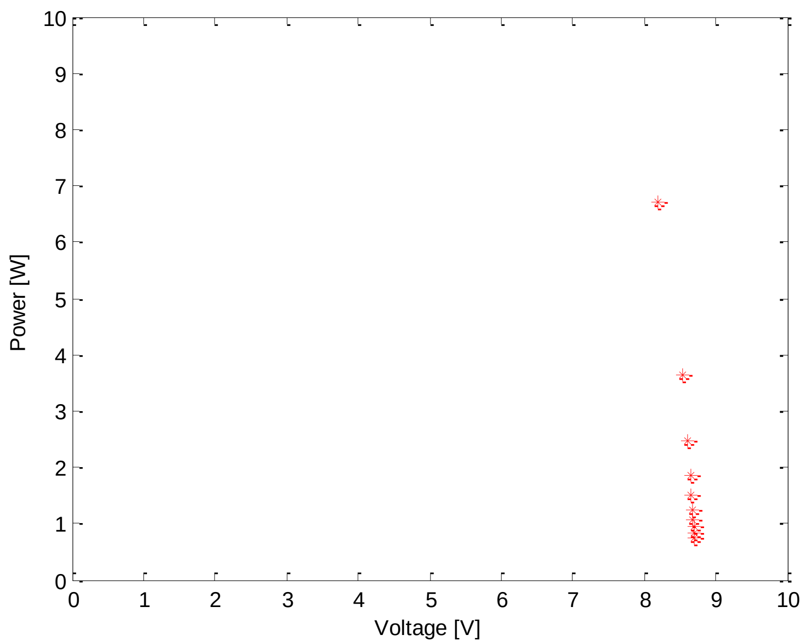


Figure 18: Power in function of the voltage for the solar panel.

We see that the power is the highest for a resistor of 10 Ohm in the series of resistors from 10 to 100 Ohm. We cannot compare these results with our measurements because our measurements are not correct.

Simulation of the car without solar panel.

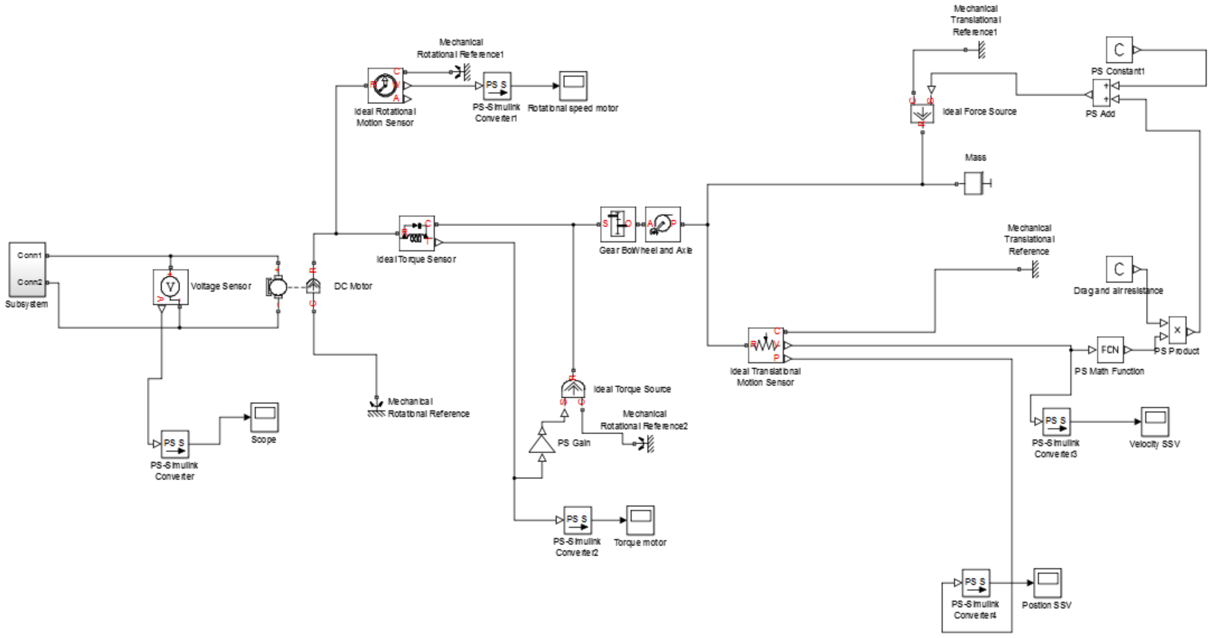


Figure 19: The simulation without the solar panel with the resistances

$$v = \sqrt{hg}$$

If the height of the ball is 1 m, the starting speed of the car will be 3.13 m/s. If we plot this to find the total distance the car drives, we find the following result.

Combined simulation.

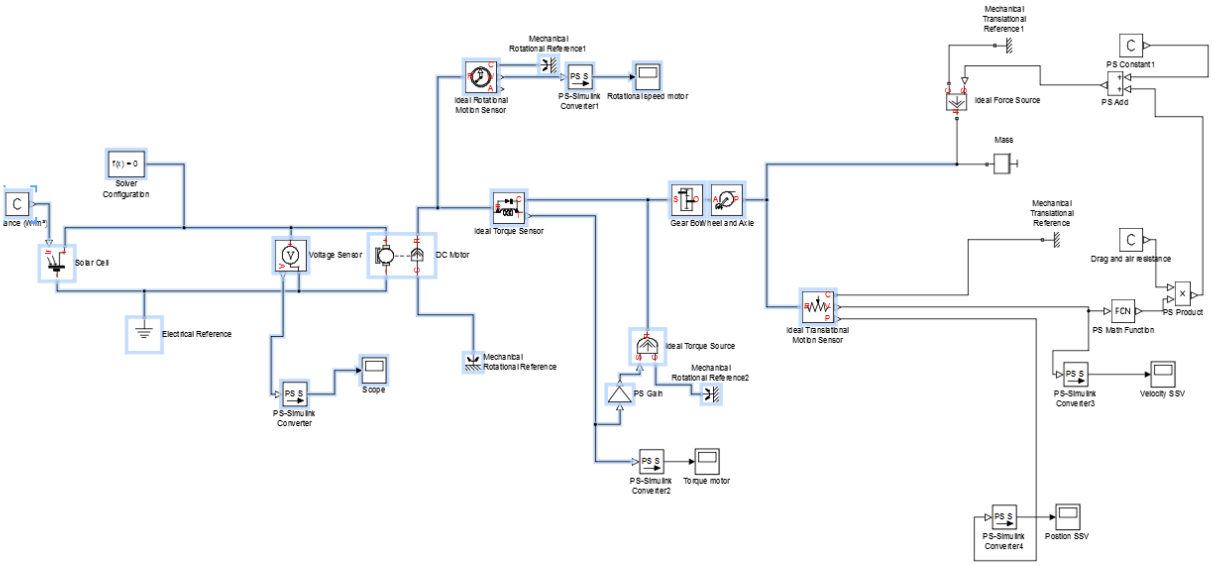


Figure 20: The simulation with all the resistances.

If we simulate the speed of the car with this model we get the following graph.

From this graph we see the ideal mass and gear ratio is:

$$m =$$

$$gear\ ratio =$$

Why a simulation?

In a simulation you can easily change parameters and get instantly the results. You can easily simulate different situations and compare them and get the ideal values of the car. With these we can avoid a very long trial and error process of building the car. The results will also be more accurate because we make less assumptions in the simulation. With a simulation we predict the outcome of the race.